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EXPERIMENTAL DUNE RESTORATION AND STABILIZATION, NAUSET BEACH, --ETC(U)
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Experimental Dune Restoration and Stabilization, Nauset Beach, Cape Cod, Massachusetts

by

Paul L. Knutson

TECHNICAL PAPER NO. 80-5

AUGUST 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In April 1970, experimental plots were established on a baymouth bar at Nauset Harbor on Cape Cod, Massachusetts. On the bar both sand fences and American beachgrass (*Ammophila breviligulata*) were tested as alternative techniques for creating and stabilizing dunes. Elevational profiles were made periodically in the test plots from April 1970 to November 1977. The study concluded that sand fences initially capture sand more rapidly than newly planted beachgrass. Once established, however, beachgrass plantings (continued)

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trap sand at a rate equivalent to multiple lifts of sand fence. Using either sand fence or beachgrass, a dune growth rate of more than 11 cubic meters per linear meter of beach per year was sustained. Crest elevation increased 0.25 meter per year.

PREFACE

This report, which describes the methods, materials, results, and conclusions of an experimental dune restoration and stabilization study on Nauset Beach, Cape Cod, Massachusetts, is published to assist engineers, municipalities, and private property owners in designing and maintaining dune restoration and stabilization projects on the North Atlantic coast. The work was carried out under the coastal ecology research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by Paul L. Knutson, a CERC coastal ecologist, under the general supervision of E.J. Pullen, Chief, Coastal Ecology Branch.

The author expresses appreciation to R. Savage and D. Woodard, who initiated the experiment and monitored the early progress of the work, and S. Onysko of the U.S. Army Engineer Division, New England, who managed, inspected, and maintained the project throughout the experimental period and reviewed the final draft. A.K. Hurme of CERC conducted periodic site inspections and A. Meyer, J. Ford, and D. Knight, CERC, performed much of the data reduction. Dr. W.W. Woodhouse, North Carolina State University at Raleigh, reviewed and commented on the original manuscript.

U.S. Army Engineer Division, New England, acknowledges the cooperation and assistance in this experiment by personnel of other Federal offices and agencies, by State, municipal and local authorities, and by other individuals, particularly the following: U.S. Department of Interior, National Park Service, Cape Cod National Seashore; U.S. Department of Interior, Wellfleet Job Corps; U.S. Department of Agriculture, Soil Conservation Service, Hyannis, Massachusetts; Stephen L. French Forestry Camp, Nicherson State Park, East Brewster, Massachusetts; Selectmen, Towns of Orleans, Eastham, and Chatham; G. Munsey, R. Frostholm, W. Goff, and E.M. Richardson; Town of Orleans; and R.C. Kelsey, aerial photographer, Chatham, Massachusetts.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

Ted E. Bishop

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

EXPERIMENTAL DUNE RESTORATION AND STABILIZATION,
NAUSET BEACH, CAPE COD, MASSACHUSETTS

by
Paul L. Knutson

I. INTRODUCTION

1. General.

Many coastal harbors and waterways are sheltered by sandbars, sandspits, and barrier beaches--formations which absorb the brunt of wave attack during severe storms. One or more natural inlets through these bars and beaches often provide navigational access to the ocean. These inlets may migrate considerable distance over time as old inlets are filled by littoral drift processes and new inlets are formed by storms. Newly formed or recently disturbed parts of barrier formations are typically unstable, consisting of unconsolidated sands and gravel. More mature reaches may support stands of beach grass and other vegetation which trap blowing sand and build dunes, providing a measure of stability. However, severe storms, grazing, and foot and vehicular traffic may degrade even mature areas and make them unstable.

In some cases, barren parts of emergent formations contribute significant quantities of windblown sand to the bays or lagoons they protect, often causing an increase in maintenance dredging requirements and damaging navigation channels and shellfish beds. In addition, the instability of these areas may constitute a threat to existing facilities. In such cases, considerable benefit may be realized by encouraging and accelerating the natural barrier beach formation and stabilization processes.

This study evaluates the effectiveness of several alternative stabilization techniques on a newly formed barrier beach.

2. Study Objectives.

The objectives of the experiment at Nauset Beach (Fig. 1) were to (a) determine if standard methods of dune restoration and stabilization, developed along the gulf and South Atlantic coasts, could be applied to the North Atlantic coast, and (b) determine the best methods and materials needed in the design and construction of dune stabilization projects. More specific information on materials, techniques, maintenance, and costs is provided in Knutson (1977) and Woodhouse (1978).

3. Previous Work.

a. General. Considerable research has been conducted to develop workable sand stabilization techniques for use in (a) creating or restoring dune systems as barriers to the inland penetration of waves and storm surges, and (b) slowing or halting the inland migration of coastal dunes. The most widely used techniques involve the installation of wooden or fabric fences and the planting of native beach grasses.

Wooden or fabric fences create a region of low wind velocity which causes wind-transported materials to deposit and accumulate. The most commonly used

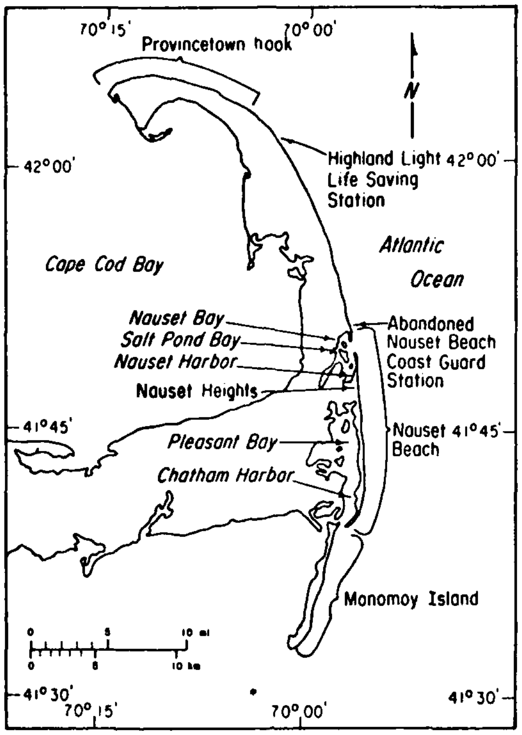

Figure 1. Location of study area at Cape Cod, Massachusetts.

and easily attainable sand fencing material is the standard, slat snow fencing normally used to prevent snow from drifting onto highways. This fencing is made of wooden slats 3.8 centimeters wide and 1.2 meters long, bound in a parallel series with steel wire. The fencing has a porosity of about 50 percent and can be rolled up for ease in transporting.

Beach grasses also create a region of low wind velocity. Most coastal dune systems are naturally created and maintained by beach grasses which trap and hold blowing sand. Planting of beach grass for sand stabilization originated in the United States more than 150 years ago in Provincetown, Massachusetts, about 40 kilometers north of the Nauset Beach experimental site (Fig. 1). The most commonly used beach grass on the North Atlantic coast is American beachgrass (*Ammophila breviligulata*). This plant grows naturally from Maine to North Carolina and in the Great Lakes region.

b. Studies of Sand Fences and American Beachgrass. Coastal Engineering Research Center (CERC) and its predecessor, the Beach Erosion Board (BEB), conducted sand stabilization experiments on the Outer Banks of North Carolina during the 1960's (Savage, 1963; Savage and Woodhouse, 1968). These studies documented considerable information on the relative effectiveness of American beachgrass and sand fencing schemes. The results of those studies are presented to provide a framework to assess the results of the Nauset Beach study.

Savage (1963) tested the effectiveness of several fence configurations, including (a) straight sand fence, (b) sand fence in a zigzag pattern, and

(c) straight sand fence with 1.5-meter-perpendicular side spurs erected at 15-meter intervals in the North Carolina experiments. All fences were installed parallel to the shoreline. Over a 9-month period, he found sand accumulation highest in the straight fence section.

Savage and Woodhouse (1968) furthered the dune building processes by using multiple lifts of sand fencing to construct larger dunes. After the first fence had filled with sand, a second fence was constructed two-thirds of the distance up the seaward face of the accumulation. A third fence was erected after the second had filled, etc. Over a 39-month observation period, three lifts of fencing trapped an average of 0.75 cubic meter per linear meter per month. These experiments demonstrated that sand trapping could be sustained with successive lifts of fencing.

The North Carolina experiments also assessed the sand-trapping capabilities of planted American beachgrass. Beachgrass plots were planted at spacings of 40 by 50 centimeters and 60 by 60 centimeters to a width of 24 meters. Although the plot with closer spacing initially trapped more sand, total sand accumulation after 37 months was nearly the same for both spacings. In comparison, the American beachgrass (40- by 50-centimeter spacing) trapped 0.70 cubic meter per meter per month, nearly the same rate trapped by the multiple lifts of sand fencing (Savage and Woodhouse, 1968).

c. Sand Stabilization on Cape Cod. The earliest example of the use of beach grass for sand stabilization in the United States was on Cape Cod. Between 1830 and 1839 more than 550 hectares of land near Provincetown (Fig. 1) was planted to restabilize areas destroyed by foresting and cattle grazing.

In 1962, the Great East Coast Storm of March 1962 caused extensive damage along the Atlantic seaboard. Following the storm, there was increased interest in dune restoration on Cape Cod. Several trial installations of sand fencing and beachgrass plantings were made by State and Federal agencies and private groups (Zak, 1967; U.S. Army Engineer Division, New England, 1968). A summary of these projects is included as Appendix A.

II. DESCRIPTION OF THE STUDY AREA

1. Geography and Geomorphology.

Nauset Beach, a highly scenic 32-kilometer stretch of sandy beach, is located on the "forearm" of the compound spit of Cape Cod (Fig. 1). The shoreline of Cape Cod is composed of unconsolidated sand, gravel, clay, and boulder deposited by retreating glaciers; bedrock is 122 to 152 meters below sea level. The unconsolidated shoreline is easily eroded by waves, tidal currents, and winds. Relic marine scarps or cliffs 18 to 30 meters high are located between the Highland Light Life Saving Station southeast of Provincetown and the abandoned U.S. Coast Guard Station at the north end of Nauset Beach (Fig. 1). These cliffs retreat at a rate of about 0.6 to 1.2 meters per year. Sands from the cliffs are carried by waves in both north and south directions (Zeigler, 1960). Sands transported north have created the Provincetown hook; those moved south have formed Nauset Beach and Monomoy Island (Fig. 1). The Nauset Beach area includes a series of barrier beaches which shelter Nauset Bay, Salt Pond Bay, Nauset Harbor, Pleasant Bay, and Chatham Harbor. Nauset Harbor connects with the ocean through a migrating inlet which divides the bar into two spits, the north spit and the south spit (Fig. 2). The experimental project is located on the south spit.

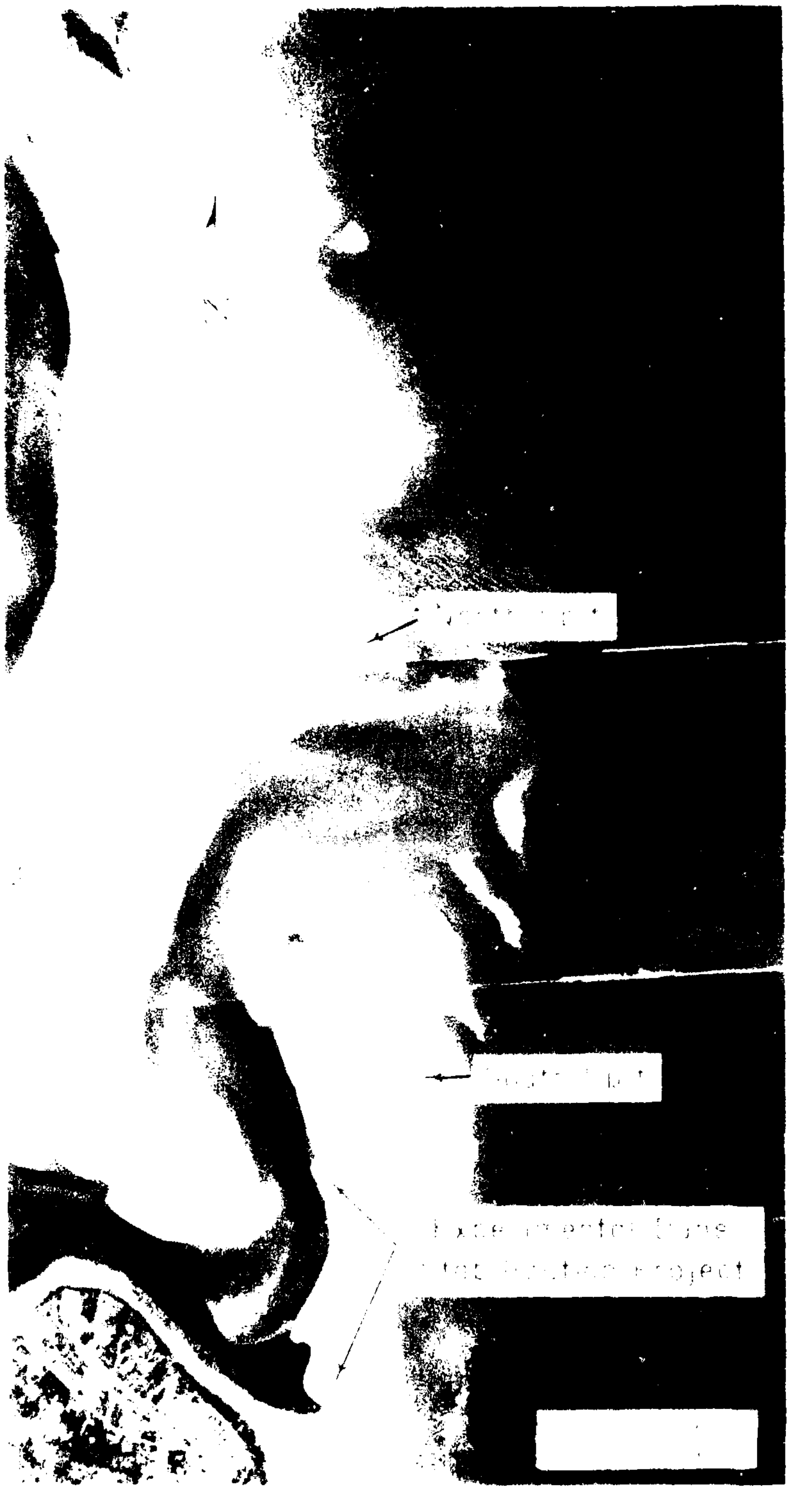

Figure 2. Inlet at Nauset Harbor, October 1969.

From 1856 to 1940 the inlet was located at the south end of the harbor near Nauset Heights. In 1941 the south spit grew northward and the inlet shifted approximately 1.6 kilometers to the north (Zeigler, 1958). Between October 1957 and April 1958, wave action reduced the tip of the south spit from approximately 1,234 to 564 meters (Zeigler, 1958). By 1969, the south spit was approximately 853 meters long, and the inlet was migrating northward.

2. Climate.

The Cape's proximity with the marine environment produces a moderate climate. Precipitation occurs more than 90 days per year, averages about 100 centimeters, and is evenly distributed throughout the year. During summer, average daily maximum temperatures are below 26° Celsius.

Wind records from Boston, about 100 kilometers to northwest of Nauset Beach, and shipboard observations are summarized in Table 1. These records indicate that mean annual windspeed on Cape Cod is probably from 20 to 25 kilometers per hour. The Cape has a distinct seasonal wind pattern. Strongest winds occur during the winter months, generally from the west to northwest. Winds are more moderate during other seasons and generally prevail from the west and southwest.

Table 1. Monthly mean windspeeds and prevailing directions, compiled from airport records and shipboard observations.[1]

Month	Mean windspeed (km/hr)		Prevailing direction	
	Airport record	Shipboard obsns.[2]	Airport record	Shipboard obsns.
Jan.	23.2	33.9	NW.	NW.
Feb.	23.3	30.3	WNW.	W.
Mar.	23.2	29.9	NW.	W.
Apr.	21.7	24.1	WNW.	W.
May	20.1	21.1	SW.	SW.
June	18.7	19.8	SW.	SW.
July	18.0	16.5	SW.	SW.
Aug.	18.0	18.8	SW.	SW.
Sept.	18.5	22.0	SW.	NE.
Oct.	19.8	24.4	SW.	W.
Nov.	21.4	28.0	SW.	W.
Dec.	22.5	34.2	WNW.	NW.

[1]Fifteen-year record, Logan International Airport, Boston, Massachusetts (from Brodhead and Godfrey, 1977).

[2]Observations recorded from 1963 to 1971, Quonset Point Area 13 (U.S. Naval Weather Service Command, 1975).

3. Tides.

Tides in Nauset Harbor are complex due to the shape and size of the inlet and the figuration of natural channels throughout the large marsh areas. The tidal range is 0.67 meter in Nauset Bay and 1.31 meters just inside Nauset Inlet. The ocean tidal range outside of the inlet is 1.83 meters (S. Onysko, U.S. Army Engineer Division, New England, personal communication, 1979).

III. METHODS AND PROCEDURES

Field experiments at Nauset Beach were initiated in 1969. Test plots were first established on the Nauset Harbor north spit (Fig. 2). However, during the first year the inlet continued to migrate north obliterating part of the study area (Fig. 3). Since loss of part of the experiment would have negated the study results, the north spit plots were abandoned and new plots were established on the south spit (Fig. 4) in April 1970.

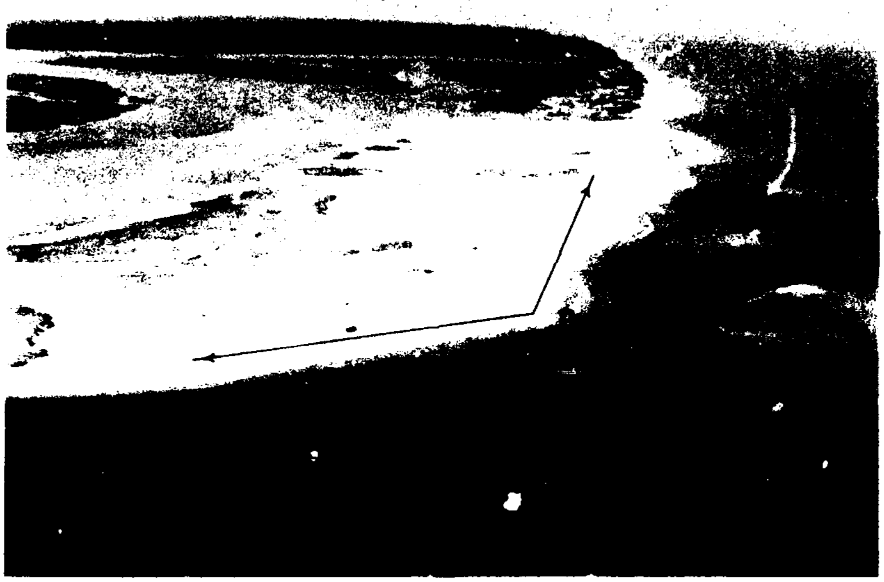

Figure 3. Nauset Harbor (north spit) abandoned test site, October 1969.

1. Experimental Design.

In April 1970, the south spit was approximately 850 meters long and 180 meters wide. Scattered patches of American beachgrass grew along the landward edge of the spit, extending northward for about 600 meters. The remainder of the spit was unvegetated. Crest elevations along the spit decreased from south to north at a slope of about 1 on 400.

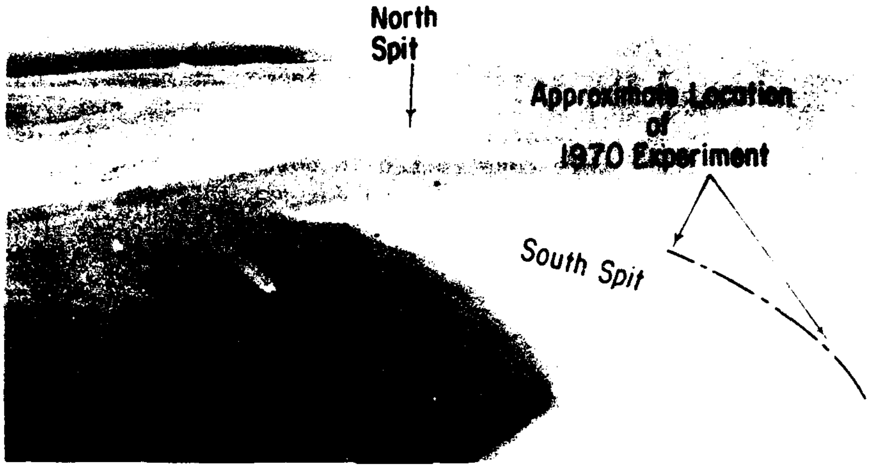

Figure 4. Nauset Harbor (south spit), October 1969.

Five plots were established roughly parallel to the beach in a north-south direction 60 to 90 meters from the seaward shore (Fig. 5). No space was left between plots to avoid creating a natural pathway for washovers. To minimize error due to end or shadow effect, an extensive plot length of 150 meters was used. American beachgrass was planted in plots 1, 3, and 5 on 45-, 60-, and 90-centimeter centers, respectively. Sand fences with side spurs were tested in plot 2 and straight sand fences were tested in plot 4. There were no replications of the test conditions.

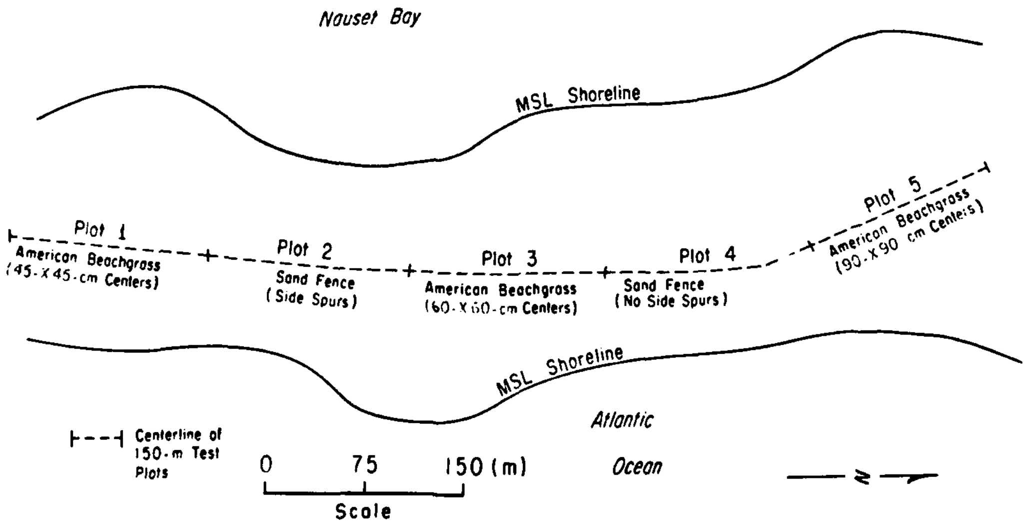

Figure 5. Location of five test plots at Nauset Beach.

2. Installation.

a. Beachgrass Plots. American beachgrass plantings were conducted between April and November 1970. The beachgrass was wild-harvested from existing stands on Nauset Beach near Nauset Heights. Harvested plants were separated into single sprigs (single stems with attached root material) and planted--three to five sprigs per hill.

b. Fence Plots. A single, straight sand fence was constructed in plots 2 and 4 in April 1970. In plot 2, 3-meter side spurs were added perpendicular to the straight fence at 15.3-meter intervals on alternate sides of the fence. Additional lifts of fence were constructed in both plots in January 1971 (second lift), April 1971 (third lift), and January 1972 (fourth lift). The second lift was placed about two-thirds of the way up the slope of the sand accumulated by the first lift. The third and fourth lifts were placed on the seaward and landward sides of the newly formed dune, respectively. In plot 2, side spurs were added on alternate sides of the second lift, only on the seaward side of the third lift, and only on the landward side of the fourth lift (Fig. 6). In April 1972 after the fourth lift had filled with sand, plots 2 and 4 were planted with American beachgrass on 60-centimeter centers, three to five sprigs per hill.

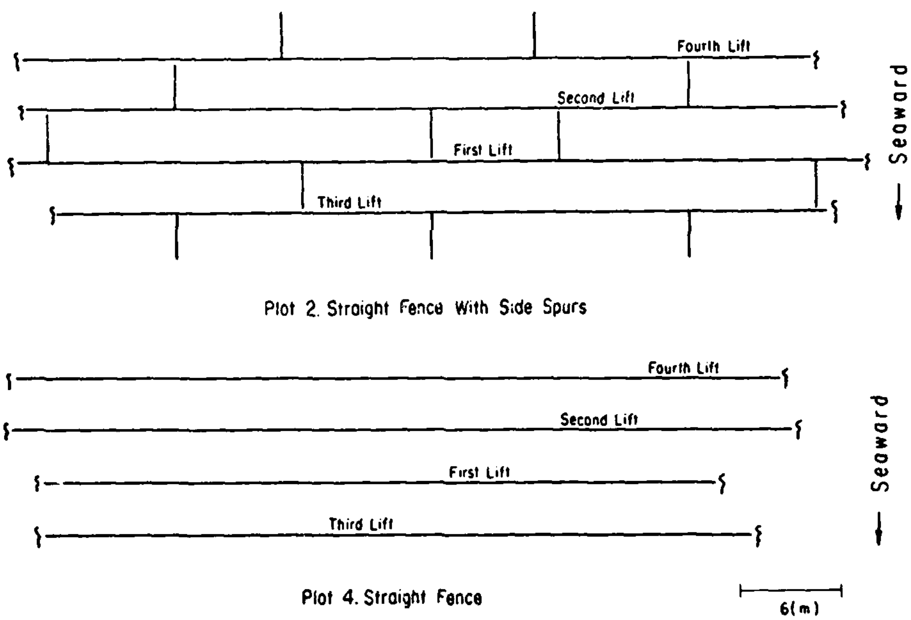

Figure 6. Fence configurations in plots 2 and 4.

3. Maintenance.

Parts of the planting areas in which survival was low were routinely replanted: plot 1, remedial planting in October 1971 and April 1972; plot 2, remedial planting in April 1973; plot 3, remedial planting in October 1971; plot 4, remedial planting in April 1973; and plot 5, remedial planting in October 1971 and April 1972. Although experimental planting was discontinued after 1973, local volunteer groups have continued to provide periodic maintenance.

Commercial fertilizer was applied to the surface of the fence and beachgrass plots as needed to encourage growth. Table 2 is a summary of fertilizer applications. Application rates varied from 5 to 25 kilograms per hectare of nitrogen. It is not known whether local groups have continued fertilizer applications.

Table 2. Fertilizer applications.

Date	Types of fertilizer	Plots fertilized
Apr. 1970	Slow release	1, 3, 5
Apr. 1971	Slow release	1, 3, 5
Aug. 1971	Slow release	1, 3, 5
Oct. 1971	30-10-10 NPK[1]	1, 3, 5
Apr. 1972	30-10-10 NPK	1 to 5
June 1972	30-10-10 NPK	1 to 5
Aug. 1972	30-10-10 NPK	1 to 5
Sept. 1972	30-10-10 NPK	1 to 5
Apr. 1973	30-10-10 NPK	1, 2, 4, 5

[1]Nitrogen, phosphorous, potassium.

4. Monitoring.

a. Elevational Surveys. A permanent base line was established roughly parallel to the long axis of the 150-meter test plots. Two cross-sectional profile lines were made across each of the plots during 11 survey periods: April 1970; January, April, and October 1971; February and October 1972; April and June 1973; April 1974; September 1975; and November 1977. Elevations were recorded to the nearest 3.6 centimeters. Profile lines are numbered consecutively from south to north. Lines 1 and 2 traverse plot 1, lines 3 and 4 traverse plot 2, etc. (Fig. 7).

The survey data were analyzed for sand accumulation rates, elevational profile changes, and shoreline migration. As a standard for direct comparison of plots, sand accumulation was calculated for an area 23 meters landward and seaward of each plot centerline for surveys up to April 1974 and 30.5 meters from each centerline for 1975 and 1977 surveys. In addition, for the beachgrass plots 1, 3, and 5 lateral spread of vegetation was measured and sand accumulation beneath vegetation was calculated.

b. Field Observations. Observations of plant growth and the condition of sand fences were recorded during each profile survey. Special damage estimates were also made following severe storms.

IV. RESULTS

During this 7-year study (1970 to 1977), Nauset south spit elongated at a rate of more than 100 meters per year. Detailed information on long-term

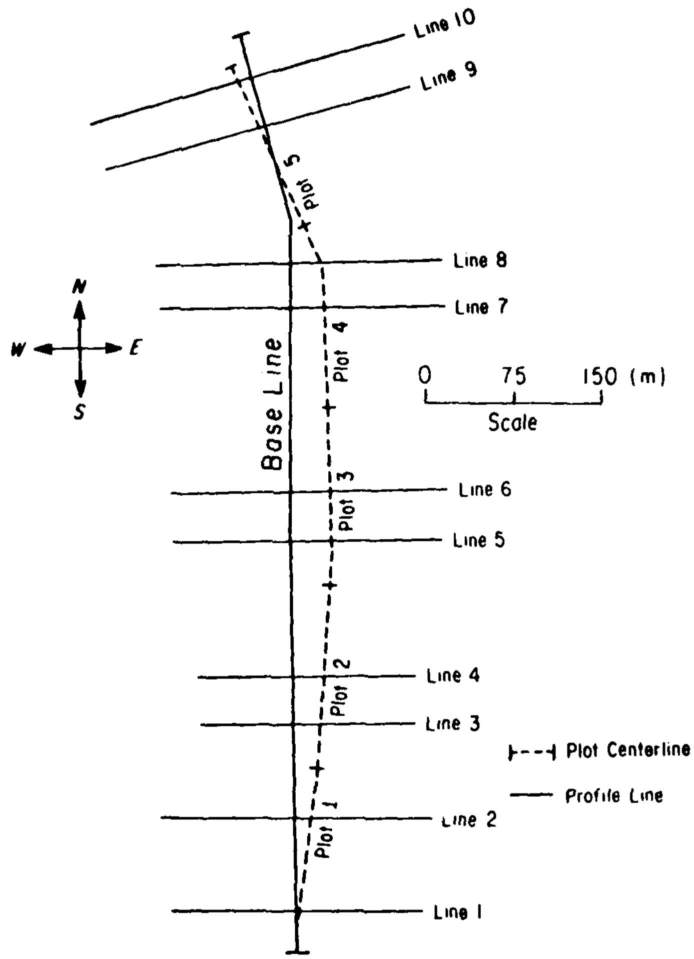

Figure 7. Cross-sectional profile locations.

patterns of erosion and accretion on the spit as well as changes associated with severe storms is given in Appendix B. The remainder of this section focuses on changes that occurred within the boundaries of five test plots.

1. American Beachgrass with 45-Centimeter Spacing (Plot 1).

a. Installation, Damage, and Repair. Plot 1 was planted with American beachgrass sprigs on 45-centimeter centers, three to five sprigs per hill in 1970. Survival of plantings during the first year was 85 percent. Bare areas were replanted in October 1971. A severe storm in February 1972 deposited 0.3 to 0.7 meter of sand in the entire planting area. Plants were observed emerging through the deposit by April 1972. It was not possible to measure the overall survival of the buried plants because bare areas were replanted in April 1972 in keeping with study objectives to provide plant cover in the test plots. Of importance, however, is that American beachgrass did emerge through at least a 0.3-meter washover deposit and did survive saltwater inundation.

b. Short-Term Dune Growth. At the end of the first complete growing season (October 1971), the crest elevation of the planted area had increased only

0.1 meter and sand accumulation was negligible. By October 1972, crest elevation had increased an average of 0.5 meter and sand accumulation was approximately 16.3 cubic meters per meter of beach. Figure 8 is a photo of the plot in May 1973.

Figure 8. Plot 1 (American beachgrass on 45-centimeter spacing), May 1973.

c. Long-Term Dune Growth. Growth of the dune at profile line 1 through November 1977, 7 years after planting, is illustrated in Figure 9. Dune width along profile lines 1 and 2 averaged about 61 meters by 1977. The landward and seaward slope along these profile lines averaged 1 on 9.5 and 1 on 15.6, respectively. Dune growth was generally in a seaward direction. The seaward shoreline showed slight accretion until 1973; thereafter, slight erosion returned the shoreline to near its original location. By 1977 the crest elevation had reached 5.5 meters mean sea level (MSL), 1.8 meters above the original planting elevation. Total sand accumulation during seven complete growing seasons was 55 cubic meters per linear meter. Figure 10 is a photo of the plot in October 1977.

d. Performance Summary. Table 3 summarizes growth characteristics of the dune in plot 1.

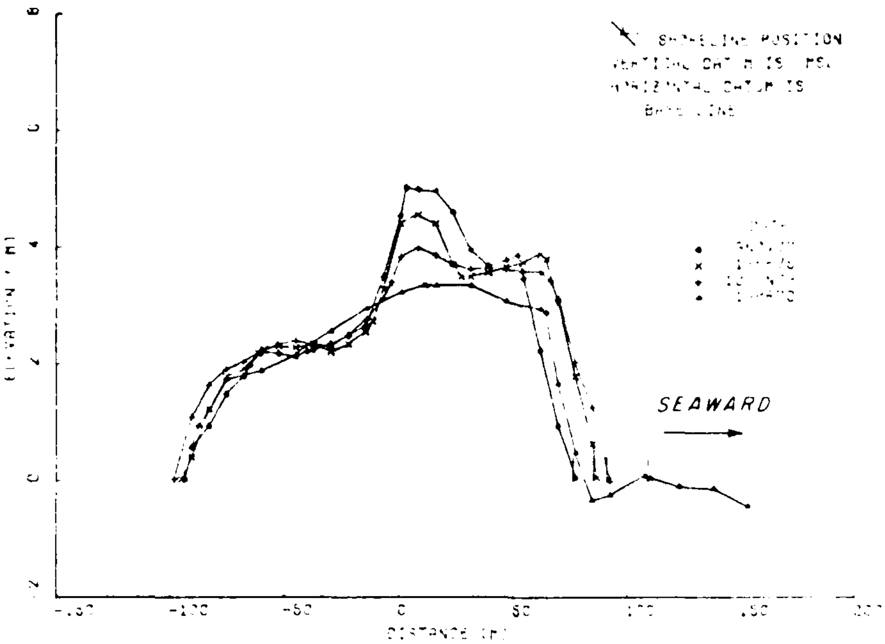

Figure 9. Surveys of profile line 1 at plot 1 (American beachgrass).

Figure 10. Plot 1 (American beachgrass), October 1977.

Table 3. Growth characteristics of American beachgrass planting, plot 1 (45-centimeter spacing), 1970-77.

Parameter	Time interval by growing season	Value
Sand accumulation or loss	One[1]	$-2.5\ m^3$/lin m
	Two[1]	$16.3\ m^3$/lin m
	Seven[2]	$55.0\ m^3$/lin m
Increase in crest elevation[3]	One	0.1 m
	Two	0.5 m
	Seven	1.8 m
Dune slope[3]		
Landward	Seven	1 on 9.5
Seaward	Seven	1 on 15.6
Base width[3]	Seven	61 m

[1]Volume calculated for area 23 meters landward and seaward of plot centerline; average of profile lines 1 and 2.

[2]Volume calculated for area 30.5 meters landward and seaward of plot centerline; average of profile lines 1 and 2.

[3]Average of profile lines 1 and 2.

2. Sand Fence with Side Spurs (Plot 2).

a. Installation, Damage, and Repair. A single, straight sand fence with side spurs was constructed in plot 2 in April 1970. Additional lifts of fence were constructed in January 1971 (second lift), April 1971 (third lift), and January 1972 (fourth lift). In April 1972 after the fourth lift had filled with sand, the plot was planted with American beachgrass on 60-centimeter centers, three to five sprigs per hill.

The first lift of fencing filled by December 1970, 8 months after installation. One year later washover damaged the southern 30 meters of fencing. The area was again overwashed in February 1972 at which time the southern 53 meters of lifts one, two, and three were destroyed in several places. The damaged fences were not repaired. By August the weakened southern section was again overwashed, and the beachgrass planting survival was low. In the northern half of the plot, however, plant survival was high. A remedial planting in the northern section was made in April 1973.

b. Short-Term Dune Growth. During the first 8 months, the first lift of fencing accumulated 11.3 cubic meters per linear meter. After 1 year the first two lifts (Fig. 11) had trapped 13.8 cubic meters and after 18 months three lifts had trapped 17.5 cubic meters. Subsequent winter storms, however, removed all accumulated material from the damaged southern section of the plot and removed about 0.9 cubic meter from the northern half. Thirty months (October 1972) after initial installation, an average of 21.3 cubic meters had been trapped by the fences and newly planted (April 1972) beachgrasses.

c. Long-Term Dune Growth. Figures 12 and 13 depict dune growth in plot 2 along profile lines 3 and 4 from 1970 to 1977. Note on these figures that a well-developed dune ridge existed landward of this plot when the study was initiated. Despite earlier damage to the southern section, by 1977 both

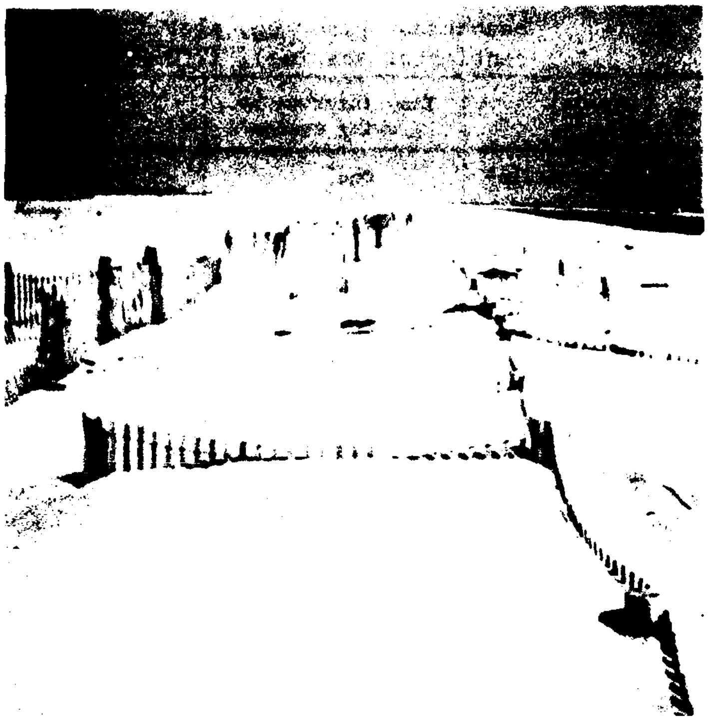

Figure 11. Plot 2 (sand fence with side spurs), March 1971.

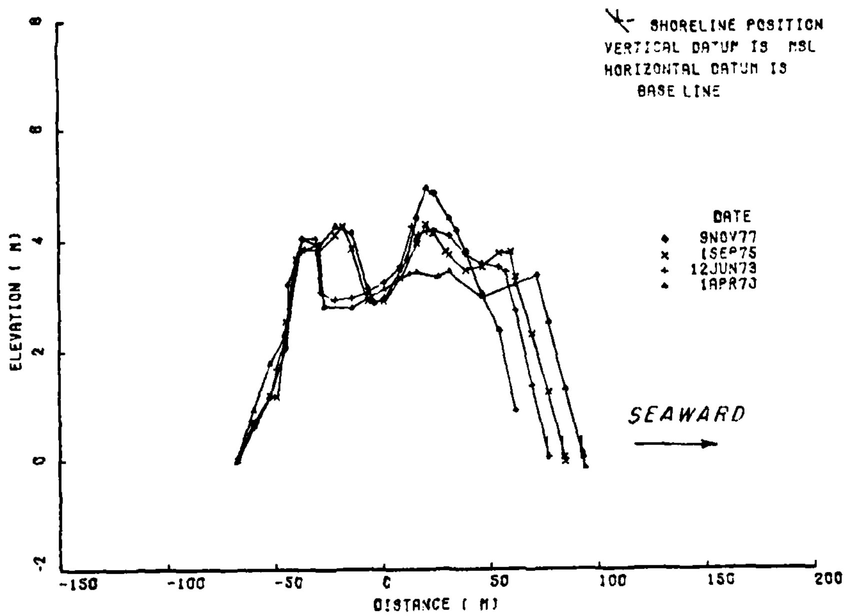

Figure 12. Surveys of profile line 3 at plot 2 (sand fence with side spurs).

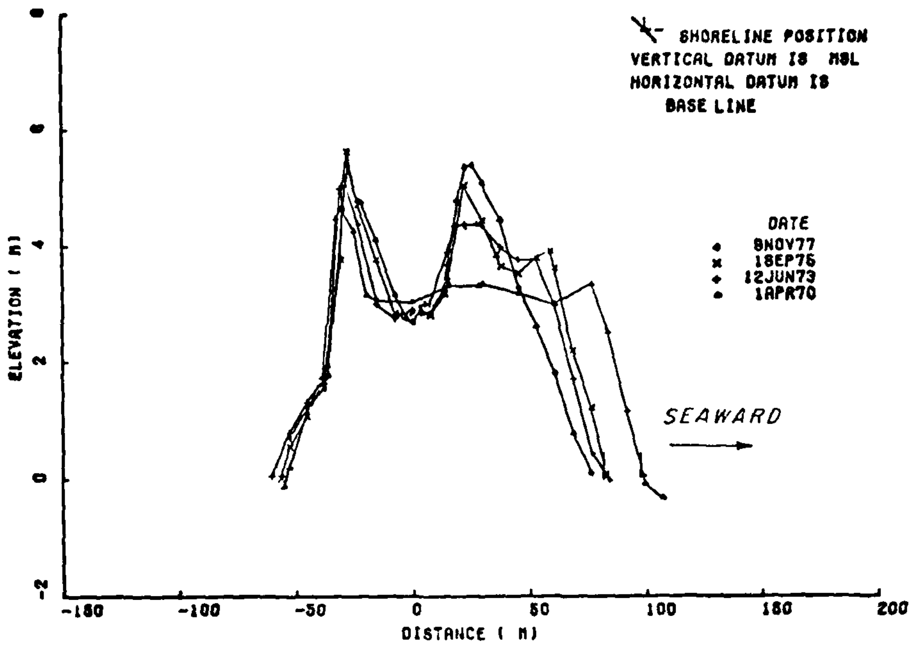

Figure 13. Surveys of profile line 4 at plot 2 (sand fence with side spurs).

segments of the plot had trapped similar amounts of sand, 30 and 35 cubic meters. Final crest elevation in the southern section was somewhat lower than the northern section, 4.9 versus 5.3 meters. Dune slope of the southern section was 1 on 15 landward and 1 on 18 seaward. Dune slope in the undamaged section was twice as steep, 1 on 7.7 landward and 1 on 7.9 seaward. Base width of the dune in 1977 was about 41.2 meters in the southern section and about 32.9 meters in the northern section. While the bayward shore remained stable, the seaward shore retreated about 25 meters during the 8 years of observation.

d. Performance Summary. Table 4 summarizes dune development from 1970 to 1977.

3. American Beachgrass with 60-Centimeter Spacing (Plot 3).

a. Installation, Damage, and Repair. Plot 3 was planted in 1970 with American beachgrass on 60-centimeter centers, three to five sprigs per hill. Survival was initially very low (about 10 percent as measured in June 1971) because of the migration of a storm berm into the planting area. The plot was replanted in October 1971. Much of the replanted area was buried with sand during a February 1972 storm and survival of the second planting was less than 20 percent the following year. Observations in May 1973 indicated that the area was replanted, possibly by local volunteer groups, though no additional planting was made as part of this study (Fig. 14). The presence of the storm berm in the planting area and evidence of overwash were observed in October 1973 and May 1974. After 1973, two washover areas became natural pathways for foot and vehicular traffic. These two thoroughfares, lying east-west, connected the seaward beach with a pathway running north-south that roughly bisected the dune longitudinally. Neither of the plot 3 profile lines (lines 5 and 6) coincide with the east-west thoroughfare; however, the north-south

Table 4. Growth characteristics of four lifts of spur fencing, plot 2, 1970-77.

Parameter	Time interval (mo)	Value
Sand accumulation	8[1]	11.3 m^3/m
	12[1]	13.8 m^3/m
	18[1]	17.5 m^3/m
	30[1]	21.3 m^3/m
	90[2]	32.5 m^3/m
Increase in crest elevation[3]	30	0.6 m
	90	1.8 m
Dune slope[3]		
Landward	90	1 on 11.4
Seaward	90	1 on 12.9
Base width[3]	90	37.2 m

[1]Volumes calculated for area 23 meters landward and seaward of plot centerline; average of profile lines 3 and 4.

[2]Volume calculated for area 30.5 meters landward and seaward of plot centerline; average of profile lines 3 and 4.

[3]Average of profile lines 3 and 4.

Figure 14. Plot 3 (American beachgrass on 60-centimeter spacing), May 1973; recent planting by local volunteer groups evident.

pathway is seen in profile line 5 (Fig. 15). Although the dune continued to accumulate sand both seaward and landward of the north-south pathway, the elevation of the path remained constant over the 5-year period from 1973 to 1977.

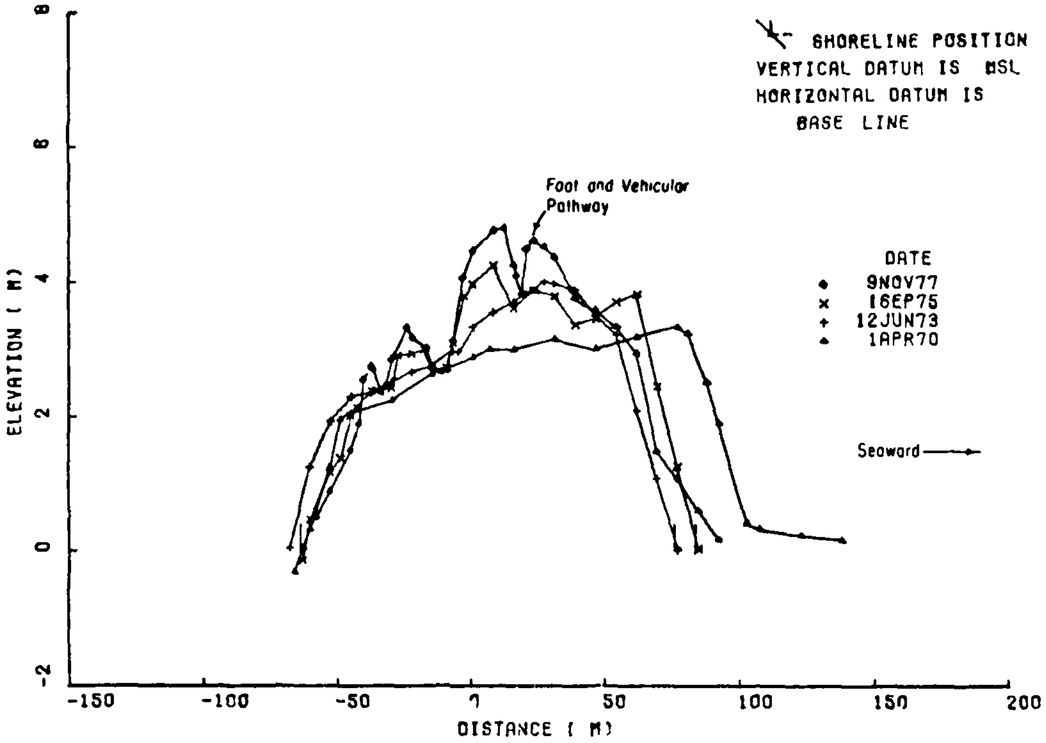

Figure 15. Surveys of profile line 5 at plot 3 (American beachgrass).

b. Short-Term Dune Growth. By the end of the second growing season (October 1972), an average of 31.3 cubic meters per meter had accumulated in the planting area. Much of this material was deposited by waves rather than by the wind. Crest elevation of the dune was 4.1 meters, 1.1 meters above the original planting surface.

c. Long-Term Dune Growth. An average of 51.3 cubic meters per meter of sand had accumulated by November 1977. Crest elevation was 4.6 meters MSL, 1.5 meters above the original planting surface, and the base width of the dune averaged 81.7 meters. The landward and seaward slopes were 1 on 21.2 and 1 on 29.7, respectively. The landward shore remained relatively stable during the study period; the seaward shore retreated about 15.0 meters over the 8 years.

d. Performance Summary. Table 5 summarizes growth characteristics for plot 3.

4. Straight Fence (Plot 4).

a. Installation, Damage, and Repair. A single, straight sand fence was constructed in plot 4 in April 1970. Additional lifts of fence were constructed in January 1971 (second lift), April 1971 (third lift), and January

Table 5. Growth characteristics of American beachgrass planting, plot 3 (60-centimeter spacing), 1970-77.

Parameter	Time interval by growing season	Value
Sand accumulation	One[1]	20.0 m^3/m
	Two[2]	31.3 m^3/m
	Seven[3]	51.3 m^3/m
Increase in crest elevation	One[4]	0.7 m
	Two[5]	1.1 m
	Seven[5]	1.6 m
Dune slope[5]		
Landward	Seven	1 on 21.2
Seaward	Seven	1 on 29.7
Base width[5]	Seven	81.7 m

[1]Volume calculated for an area 23 meters landward and seaward of plot centerline for profile line 6; no data available on profile line 5 for this survey period.

[2]Volume calculated for an area 23 meters landward and seaward of plot centerline; average of profile lines 5 and 6.

[3]Volume calculated for an area 30.5 meters landward and seaward of plot centerline; average of profile lines 5 and 6.

[4]Calculation based on profile line 6.

[5]Average of profile lines 5 and 6.

1972 (fourth lift). In April 1972 after the fourth lift had filled with sand, the plot was planted with American beachgrass on 60-centimeter centers, three to five sprigs per hill. This fence plot sustained little damage during the experiment.

b. Short-Term Dune Growth. The first lift of fence trapped approximately 12.5 cubic meters per meter by January 1971 when the second lift was installed. After 1 year, a total of 21.3 cubic meters per meter had been trapped by the first two lifts (Fig. 16). By May 1973 the four lifts of fencing in combination with the beachgrass planted in April 1972 had trapped 42.5 cubic meters per meter. Figure 17 shows the plot in May 1973, 30 months after initial installation.

c. Long-Term Dune Growth. Figure 18 illustrates the continued growth of the straight fence dune through November 1977. Although the crest elevation continued to increase, there was little net accumulation after October 1972. In general, the dune became progressively narrower due to erosion of the shoreline. By 1977, crest elevation was 3.1 meters above the plot elevation in 1970. Dune width was only an average of 30.1 meters and the landward and seaward slopes of the dune were a steep 1 on 5.8 and 1 on 4.3, respectively. The seaward shore retreated approximately 21.0 meters during the 8 years of observation.

d. Performance Summary. Table 6 summarizes dune development from 1970 to 1977.

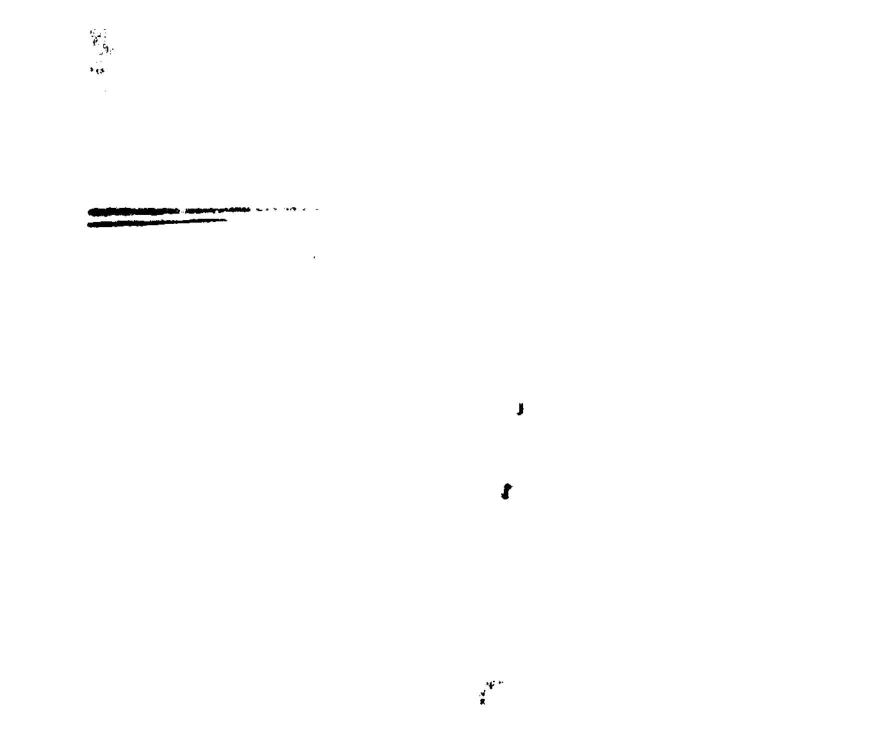

Figure 16. Plot 4 (straight fencing), March 1971.

Figure 17. Plot 4 (straight fencing), May 1973.

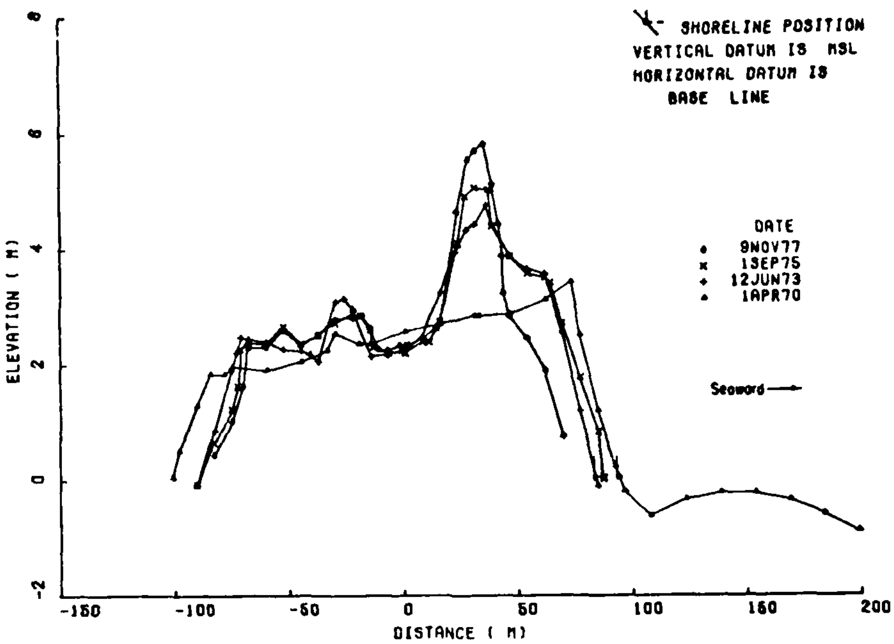

Figure 18. Surveys of profile line 7 at plot 4 (straight sand fence).

Table 6. Growth characteristics of four lifts of straight fencing, plot 4, 1970-77.

Parameter	Time interval (mo)	Value
Sand accumulation	8[1]	12.5 m^3/m
	12[1]	21.3 m^3/m
	18[1]	21.3 m^3/m
	30[1]	42.5 m^3/m
	65[1]	48.8 m^3/m
	90[2]	45.0 m^3/m
Increase in crest elevation[3]	30	2.0 m
	90	3.1 m
Dune slope[3]		
Landward	90	1 on 5.8
Seaward	90	1 on 4.3
Base width[3]	90	30.2 m

[1]Volume calculated for area 23 meters landward and seaward of plot centerline; average of profile lines 7 and 8.

[2]Volume calculated for area 30.5 meters landward and seaward of plot centerline; average of profile lines 7 and 8.

[3]Average of profile lines 7 and 8.

5. American Beachgrass with 90-Centimeter Spacing (Plot 5).

a. Installation, Damage, and Repair. Plot 5 was planted in 1970 with American beachgrass on 90-centimeter centers, three to five sprigs per hill. Planting survival in June 1971 measured 60 to 70 percent. Bare areas were replanted in October 1971. The severe storm of February 1972 deposited a veneer of sand over the plantings. Areas of low survival were replanted in April 1972.

b. Short-Term Dune Growth. Sand accumulation was negligible at the end of the first growing season. After two growing seasons 10 cubic meters per meter had accumulated and the crest elevation was 2.9 meters, 0.9 meter above the initial planting surface (Fig. 19).

Figure 19. Plot 5 (American beachgrass on 90-centimeter spacing), May 1973.

c. Long-Term Dune Growth. Figure 20 illustrates the growth of the dune from 1970 to 1977. A small secondary dune ridge had formed landward of the test area by 1973. After seven growing seasons, 55 cubic meters per meter had accumulated and the crest elevation was 3.9 meters, about 2.0 meters above the original planting surface. Most of the sand accumulation was seaward of the centerline of the plot. Base width of the dune in 1977 was very broad, averaging 96.3 meters. The landward and seaward slopes of the dune were 1 on 8.7 and 1 on 9.8, respectively. The bay shoreline remained relatively stable during the experiment; the seaward shoreline receded approximately 28.5 meters.

d. Performance Summary. Table 7 summarizes the growth characteristics of plot 5.

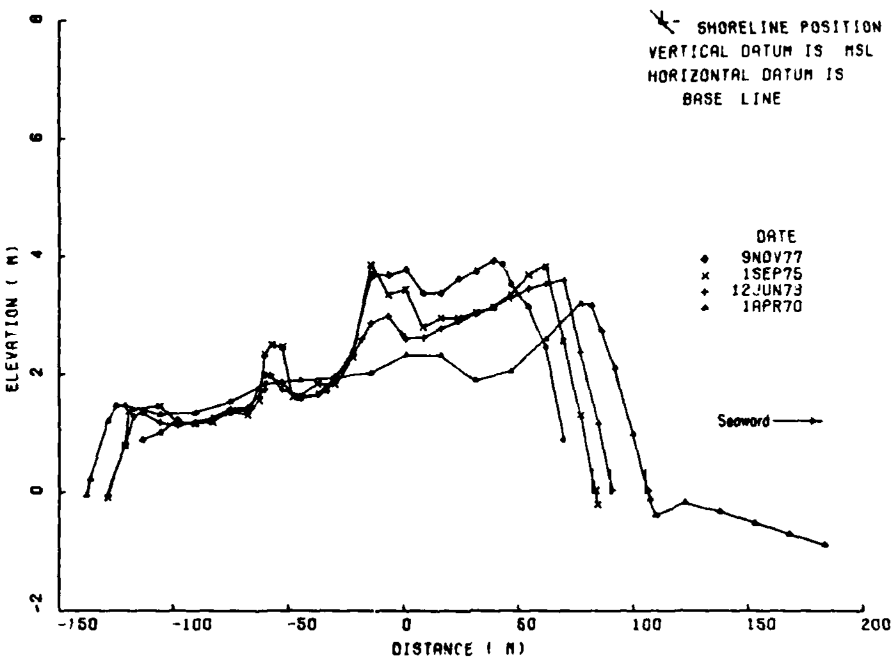

Figure 20. Surveys of profile line 9 at plot 5 (American beachgrass).

Table 7. Growth characteristics of American beachgrass planting, plot 5 (90-centimeter spacing), 1970-77.

Parameter	Time interval by growing season	Value
Sand accumulation or loss	One[1]	-3.8 m^3/m
	Two[1]	10.0 m^3/m
	Seven[2]	55.0 m^3/m
Increase in crest elevation[3]	One	0.8 m
	Two	0.9 m
	Seven	2.0 m
Dune slope[3]		
Landward	Seven	1 on 8.7
Seaward	Seven	1 on 9.8
Base width[3]	Seven	96.3 m

[1]Volume calculated for area 23 meters landward and seaward of plot centerline; average of profile lines 9 and 10.

[2]Volume calculated for area 30.5 meters landward and seaward of plot centerline; average of profile lines 9 and 10.

[3]Average of profile lines 9 and 10.

V. DISCUSSION

1. Comparison of American Beachgrass Spacing Schemes.

American beachgrass plots were planted to a standard width of 15 meters. Plants in plot 1 were spaced 45 centimeters apart; plants in plots 3 and 5 were spaced 60 and 90 centimeters apart, respectively. In October 1977, the lateral growth of vegetation was measured along each profile line. Table 8 summarized the observations made at each beachgrass plot.

Table 8. Width of American beachgrass in beachgrass plots, October 1977.

Plot No.	Description	Profile line	Width[1] (m)
1	American beachgrass (45- by 45-centimeter spacing)	1 2	71.3 65.2
3	American beachgrass (60- by 60-centimeter spacing)	5 6	48.5 31.7
5	American beachgrass (90- by 90-centimeter spacing)	9 10	89.9 78.0

[1]After seven growing seasons.

Woodhouse, Seneca, and Broome (1976) report that in North Carolina, American beachgrass spreads in the direction of sand supply at a rate of 2.4 to 3.0 meters per year. This spreading rate was exceeded in two of the three beachgrass plots in the Nauset experiment. Vegetation in plots 1 and 5 extended laterally an average of 3.8 and 4.9 meters per year. Vegetation in plot 3 spread more slowly. Plot 3, which has the foot and vehicular pathways, was badly damaged in 1971 and 1972; survival of the initial and followup plantings was only 10 to 20 percent. Initial survival in plots 1 and 5 was high, 70 to 85 percent, which accounts for the greater spread observed in these plots. Seaward spread of the vegetation in the three plots averaged 2.4 meters per year; landward spread was 4.8 meters per year. Winds are predominantly from the west during the growing season; therefore, vegetative spread was greatest in the windward direction. This observation supports that of Woodhouse, Seneca, and Broome (1976) concerning the rapid spread of American beachgrass in the direction of sand supply.

Table 9 summarizes the volume of sand accumulated under beachgrass and the overall increase in crest elevation after seven growing seasons at each beachgrass plot. The sand volume and the elevation increase in each plot are closely related to the width of vegetation in each plot (Table 8). The greatest lateral spread of vegetation and largest sand accumulation occurred in plot 5, the plot with the greatest exposure to windblown sand. In addition to landward and seaward beaches which contributed sand to all plots, plot 5 benefited by

Table 9. Sand accumulation under beachgrass and increase in crest elevation in American beachgrass plots.

Plot No.	Description	Sand accumulation[1] (m³/m)	Increase in crest elevation[1] (m)
1	American beachgrass (45- by 45-centimeter spacing)	51.4	1.8
3	American beachgrass (60- by 60-centimeter spacing)	43.9	1.6
5	American beachgrass (90- by 90-centimeter spacing)	78.2	2.0

[1]After seven growing seasons.

the elongation of the spit which provided an almost limitless supply of sand from the northern quadrant. Supporting this contention is the fact that twice the amount of sand was accumulated by the beachgrass in the northern half (profile line 10) of plot 5 as compared to the southern half (profile line 9), 100.1 versus 56.3 cubic meters per meter. Sand accumulation in the southern half of plot 5 was very similar to that in plot 1 (51.4 cubic meters per meter). From this experiment, there is no evidence to support that close (45 by 45 centimeters) or wide (90 by 90 centimeters) spacing measurably influenced dune growth. Zak (1967) also concluded that 90-centimeter spacing was adequate except in areas of severe erosion.

2. Comparison of Sand Fence Schemes.

Table 10 summarizes sand accumulation and increase in crest elevation in the spur (plot ^) and straight (plot 4) fence sections.

Table 10. Sand accumulation and increase in crest elevation in spur and straight fence plots.

Plot No.	Description	Time interval (mo)	Sand accumulation (m^3/m)	Increase in crest elevation (m)
2	Sand fence with side spurs	8 (Jan. 1971)	11.3	0.9
		18 (Oct. 1971)	17.5	1.2
		90 (Nov. 1977)	32.5	1.8
4	Sand fence with straight sections	8 (Jan. 1971)	12.5	1.1
		18 (Oct. 1971)	21.3	1.3
		90 (Nov. 1977)	45.0	3.0

The first lift of fencing was constructed in each plot in April 1970. Eight months after installation, sand accumulation was slightly higher in the straight fence plot (plot 4). In January and April 1971, lifts two and three were installed. By October 1971 the straight fence plot had trapped about 20 percent more material and its crest elevation had increased 10 percent more than the spur plot (plot 2). This inequity between plots may not be the direct result of fence performance. Note in Figure 13 that a secondary dune line formed landward of the spur fence plot. It is likely that the secondary dune reduced the volume of sand available from the landward beach.

In October 1971, the spur fence plot was damaged by overwash, whereas the straight fence remained intact. Comparison of the performance of the two fence schemes is meaningful only during the 18-month period before the damage occurred. During this period, there was no evidence that side spurs improved trapping efficiency or fence stability, but use of the side spurs did increase construction cost of the fence by about 20 percent.

A fourth lift of fencing was added to both plots in January 1972, and both plots were planted with American beachgrass in April 1972. By September 1975, 5 years and 5 months after installation, the straight fence plot had trapped 48.8 cubic meters per meter. This represents an annual accumulation rate of 9.0 cubic meters. Between 1975 and 1977, a slight loss of material occurred due to shoreline recession. By 1977, crest elevation in the straight fence plot had increased 3.0 meters or an average annual growth rate of 0.4 meter.

3. Comparison of American Beachgrass and Sand Fence.

Sand accumulation was negligible in the three American beachgrass plots during the first growing season (Tables 3, 5, and 7). The 20 cubic meters per meter of accumulation in plot 3 resulted from the migration of the storm berm into the planting area. Sand accumulation in the fenced plots was very high during the first year, averaging 11.9 cubic meters.

The undamaged straight fence plot trapped sand at a rapid rate of 9.0 cubic meters per year for the first 5.5 years. Though initially slow, the beachgrass plots trapped an average of 8.3 cubic meters per meter per year over seven growing seasons. These observations support conclusions by Savage and Woodhouse (1968): (a) Sand fences initially trap more sand than newly established stands of beachgrass, (b) multiple lifts of sand fencing can sustain dune growth, and (c) once established beachgrass stands trap sand at rates comparable to multiple lifts of sand fence.

There are two striking differences between the sand fence and beachgrass dunes--final base width and crest growth (Tables 3 to 7). Base width of the fence dunes was only 30 to 37 meters. The beachgrass dunes were 61 to 96 meters, two to three times the width of the fence dunes. However, crest growth was 1 meter greater in the straight fence plot than in the most successful beachgrass plot.

4. Comparison with Previous Studies.

Table 11 provides a comparison of annual sand accumulation and dune growth rates observed in this study and rates observed in previous studies at Ocracoke Island, North Carolina, Padre Island, Texas, and Clatsop Plains, Oregon. Cape

Cod and Ocracoke Island appear to be comparable dune-building environments. Growth rates observed in the Padre Island and Clatsop Plains studies were somewhat higher. Dune growth rates are likely to be greatly influenced by the broadness of the beach as a source of sand and the direction and severity of local winds.

Table 11. Comparison of annual sand accumulation and dune growth rates in Massachusetts, North Carolina, Texas, and Oregon.

Location	Crest growth (m)	Sand accumulation (m^3/m)
Nauset Beach, Cape Cod, Mass.[1]	0.25	8.3
Ocracoke Island, N.C.	0.18[2]	8.4[3]
Padre Island, Tex.[4]	0.46 0.60	10.8
Clatsop Plains, Oreg.[5]	0.27	13.7

[1]Average of American beachgrass plots 1, 3, and 5 in Table 9 (7 years growth).

[2]Woodhouse, Seneca, and Broome (1976) (10 years growth).

[3]Table 1, sections 12, 13, 14, and 16 in Savage and Woodhouse (1968) (3 years growth).

[4]Dahl, et al. (1975).

[5]Meyer and Chester (1977) (30 years growth).

Savage and Woodhouse (1968) calculated the volume of sand accumulated in four lifts of sand fence over a period of 5 years and 8 months. Annual accumulation during this period averaged 6.6 cubic meters per meter. The four lifts of straight fencing at Nauset Beach trapped 9.0 meters per meter per year over a comparable period.

VI. CONCLUSIONS

1. American Beachgrass.

a. American beachgrass was found to be effective for building dunes and stabilizing sand on Cape Cod.

b. American beachgrass spreads laterally at rates up to 4.9 meters per year. Previous studies in North Carolina reported spreading rates from 2.4 to 3.0 meters per year. Lateral spread was greater in the direction of prevailing winds. Prevailing winds are from the west on Cape Cod during the growing season.

c. American beachgrass is capable of surviving when buried to a depth of 0.3 meter by washover deposits. Beachgrass is also tolerant to saltwater inundation while dormant.

d. Average annual sand accumulation in 15-meter-wide plantings of American beachgrass was 8.3 cubic meters per linear meter during seven growing seasons. Dune height increased an average of 0.25 meter per year. These are similar to growth rates reported for North Carolina.

e. A 15-meter-wide planting, three to five sprigs per hill and 90 centimeters between hills, formed a dune 2.0 meters high and 96 meters wide at the base in seven growing seasons. The 90-centimeter spacing is both economical and effective.

f. Foot and vehicular traffic can damage American beachgrass plantings and prohibit growth in footpaths and wheel tracks, thereby reducing or preventing sand accumulation.

2. Sand Fence.

a. Multiple lifts of sand fence are effective for dune building on Cape Cod.

b. Four lifts of straight sand fence trapped sand at an annual rate of 9.0 cubic meters per meter of beach over a 5-year and 5-month observation period.

c. Four lifts of straight fence formed a dune 3.0 meters high and 30.2 meters wide in 7 years.

d. Adding side spurs to straight fencing does not measurably improve long-term fence performance and increases construction costs by about 20 percent.

3. American Beachgrass Versus Sand Fencing.

a. American beachgrass plantings trap little sand during the first growing season. Sand fences initially trap sand at a high rate, about 11.9 cubic meters per meter.

b. American beachgrass plantings, once established, trap sand at a rate comparable to multiple lifts of sand fence.

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APPENDIX A

SUMMARY OF SAND STABILIZATION FIELD TRIALS ON CAPE COD, MASSACHUSETTS

The following summary describes sand stabilization field trials in Cape Cod, Massachusetts, sponsored or initiated by the Massachusetts Department of Public Works, the Massachusetts Beach Buggy Association, the U.S. Army Engineer Division, New England, and the Coastal Engineering Research Center (S. Onysko, U.S. Army Engineer Division, New England, personal communication, 1979).

1. Massachusetts Department of Public Works.

In the early 1960's the Massachusetts Department of Public Works and the U.S. Bureau of Public Roads, in cooperation with the University of Massachusetts, initiated definitive studies on the use of American beachgrass for stabilization on Cape Cod. These studies found that beachgrass was effective in restoring damaged dunes and that plant spacing of 45 by 90 centimeters was adequate except in areas of severe erosion (Zak, 1967).

2. Massachusetts Beach Buggy Association (MBBA).

In 1963, MBBA obtained permission from the towns of Orleans and Chatham to erect 1,500 feet of sand fences on Nauset Beach to prevent overwash from cutting a channel into Pleasant Bay (Fig. A-1). The fence collected considerable sand and was successful for about 2 years. However, subsequent storms destroyed the project.

3. U.S. Army Engineer Division, New England.

In October 1965, the New England Division experimented with sand fences on Nauset Beach in conjunction with their Pleasant Bay navigation study (Fig. A-2), to determine if the dunes could be restored to prevent sand from washing into proposed navigation channels for the bay. The fence, which consisted of cedar piles tied securely with twine, was erected in a single line parallel to the beach but back from the high waterline in an attempt to build the dune forward. Sand was building slowly until a northeast storm hit the area on 9 January 1966, causing breakthroughs in the southern section amounting to about 7 percent total damage to the fence. Total sand accumulation for the entire length of fence, excluding the breakthroughs, amounted to about 15,000 cubic meters. This amount was collected over a 2.5-month period, but the bulk of it was collected during and right after the January storm. The cost of the fencing and posts was about $1,200 (1966). Volunteer labor was provided by the Wellfleet Job Corps. The estimated cost of collecting the sand was $0.50 per cubic meter.

A second row of fencing, with front spurs only, was constructed at the northern end of the project on 17 August 1966, about two-thirds of the way up the front slope of the new dune. By 11 January 1967, that fence was almost filled. By May 1967, the northern end of the sand fencing had created an artificial sand dune almost 2.3 meters high. Field visits in 1969 found beachgrass growing back naturally on the artificial dunes.

4. Coastal Engineering Research Center (CERC).

The original CERC experimental project was first established on Nauset Harbor north spit (Fig. A-3). The project was started in May 1969 and consisted of alternating plots of straight sand fence, grass plantings, fabric fence, and sand fences with spurs, each plot approximately 122 meters long. The straight

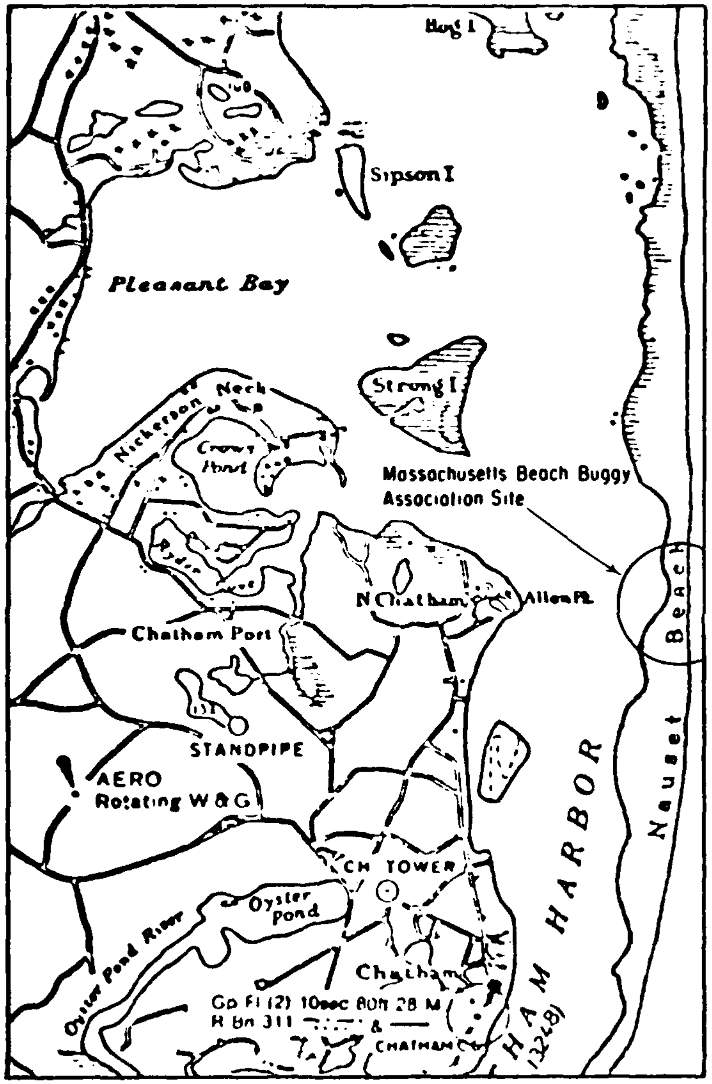

Figure A-1. 1963 Massachusetts Beach Buggy Association sand stabilization site location (NOS nautical chart No. 13246).

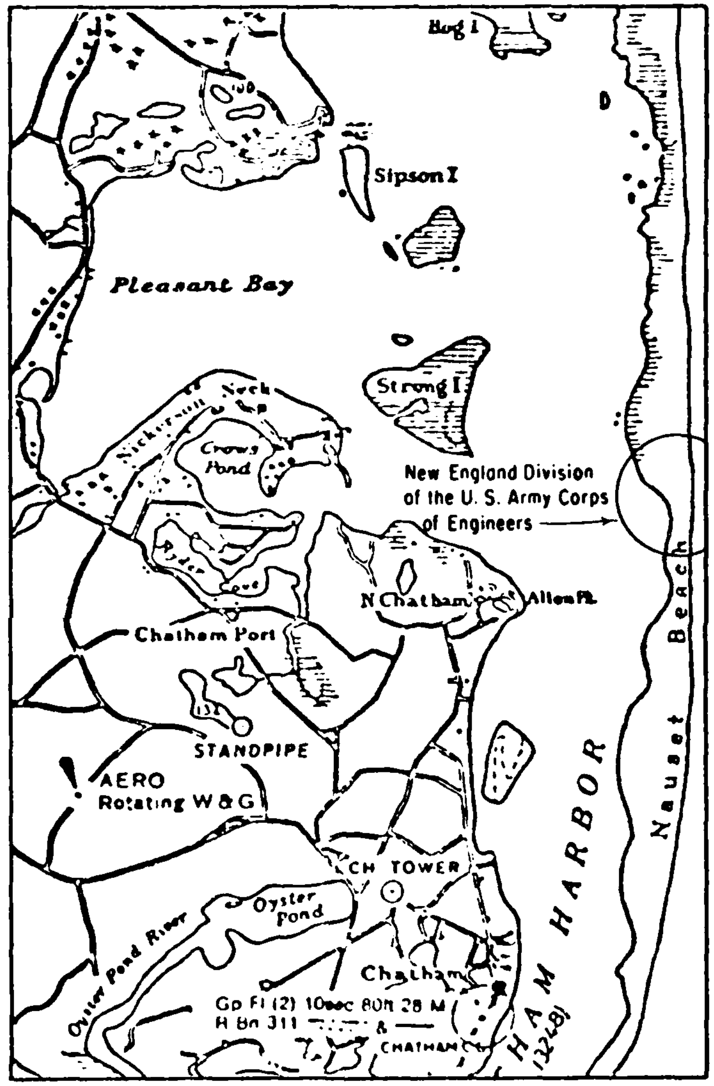

Figure A-2. Sand stabilization site location (NOS nautical chart No. 13246).

sections of fence collected very little sand due to the influence of existing dunes, which appeared to alter the wind patterns.

The planted beachgrass plots had a 95- to 98-percent mortality. The fabric fence collected sand initially but later failed structurally. The fence section with side spurs was destroyed due to the inlet shifting to the north during a coastal storm in November 1969. The CERC project was relocated to the Nauset Harbor south spit (Fig. A-3) in April 1970.

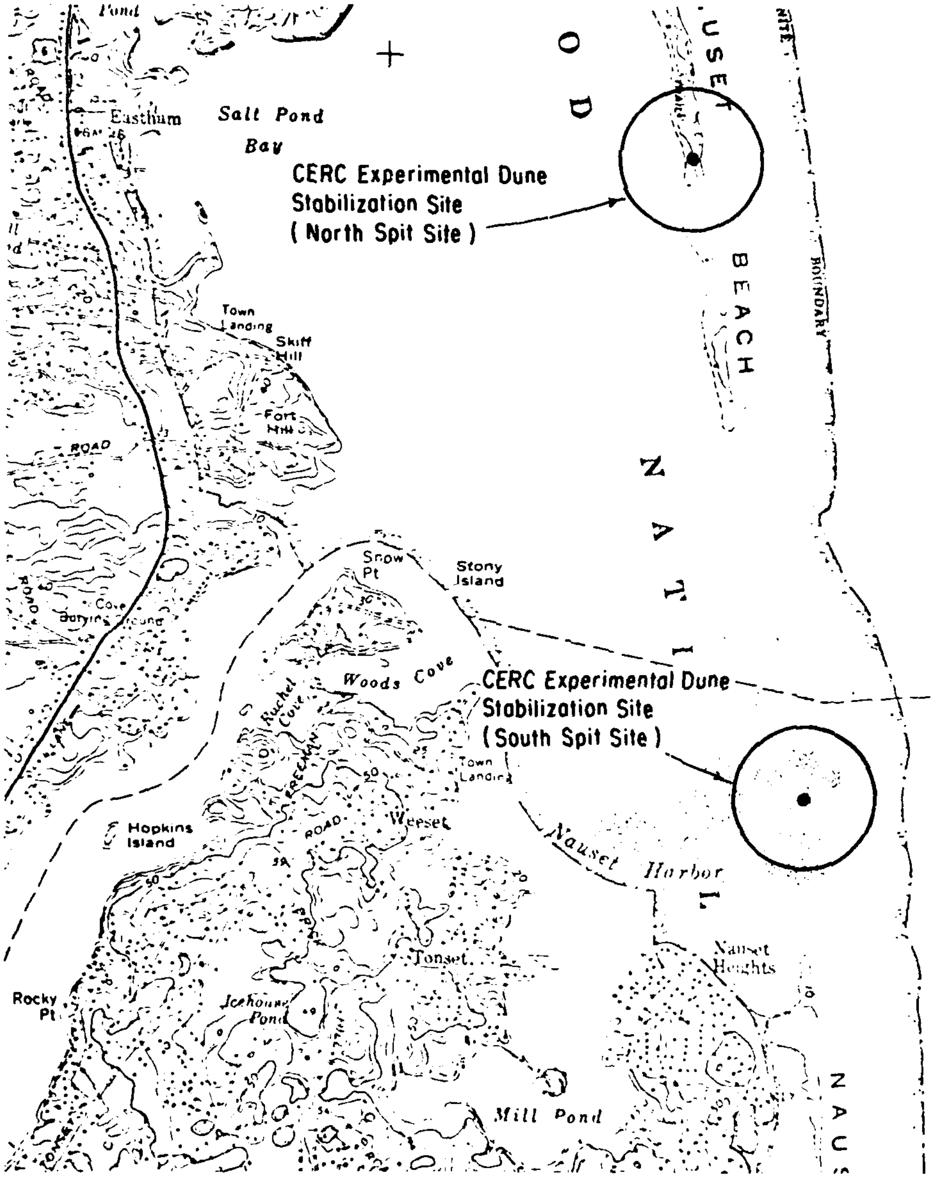

Figure A-3. 1969 north spit and 1970 south spit CERC experimental dune stabilization sites (U.S. Geological Survey).

APPENDIX B

EROSION AND ACCRETION AT NAUSET BEACH, CAPE COD

1. Storm Erosion.

a. Storm of February 1972.

(1) Description. The most severe storm encountered during the 8-year monitoring period (1970-1977) occurred 18 to 20 February 1972. Because of its intensity and long duration, the storm caused extensive damage along beaches from Long Island to New England. Storm surge reached its greatest height in the early morning hours of 19 February 1972. Surge levels of 1.3 to 1.4 meters were reported on Cape Cod (Pore, 1973). The peak storm surge was nearly coincident with high tide which intensified shore damage. Shipboard observers reported waves from 3.0 to 3.5 meters during the storm (Pore, 1973).

(2) Impact. Profile surveys were made in the study area on 14 February 1972, 4 days before the storm, and again on 6 March 1972, 14 days after the storm. Though a survey was conducted relatively soon after the storm, it should be noted that significant changes in the shore and beach may occur immediately following severe storms. For example, Birkemeier (1979) recently studied beach changes during an 18 to 20 December 1977 storm on Long Beach, New Jersey. He found that about one-half of the material eroded from the beach during the storm was returned to the beach within 2 days. The February and March 1972 profile surveys provide data on the storm impact on dunes during early stages of development. Figure B-1 depicts the prestorm and poststorm profiles on the spit. Major accretion of sand occurred along the seaward shore of profiles 1 to 4. In this area, the beach advanced from 15 to 40 meters. Though data are incomplete for profile lines 8 and 10, there appeared to be some erosion along profile lines 5 to 10, up to 15 meters at profile line 9.

During the storm the beachgrass plots (profile lines 1, 2, 5, 6, 9, and 10) were buried with overwashed sand. Plot 1 was buried by 0.3 to 0.7 meter, plot 3 by 0.03 to 0.7 meter, and plot 5 by 0.2 to 0.5 meter of sand. Plants were observed emerging in all plots by April 1972. It was not possible to measure the overall survival of the buried plants because bare areas were replanted in April 1972 in keeping with study objectives to provide complete plant cover in these areas. However, American beachgrass did emerge through at least a 0.3-meter washover deposit in plot 2 and did survive saltwater inundation. S.P. Leatherman and P.J. Godfrey (Institute for Man and Environment, National Park Service Cooperative Research Unit, University of Massachusetts, personal communication, 1979) have recently made similar observations on Nauset Beach. However, they note that saltwater inundation and overwash during the growing season can cause total mortality in American beachgrass stands. The growing season for American beachgrass is roughly from March through November (R. Zaremba, Institute for Man and Environment, University of Massachusetts, personal communication, 1979).

Crest elevations in the fenced plots were nearly 1 meter higher than the beachgrass plots before the storm. Consequently, less overwash occurred in these plots. The only major overwash occurred in plot 2. About 30 meters of the fencing in plot 2 had been damaged by a storm during the previous year. The earlier damage probably provided a natural pathway for overwash during the

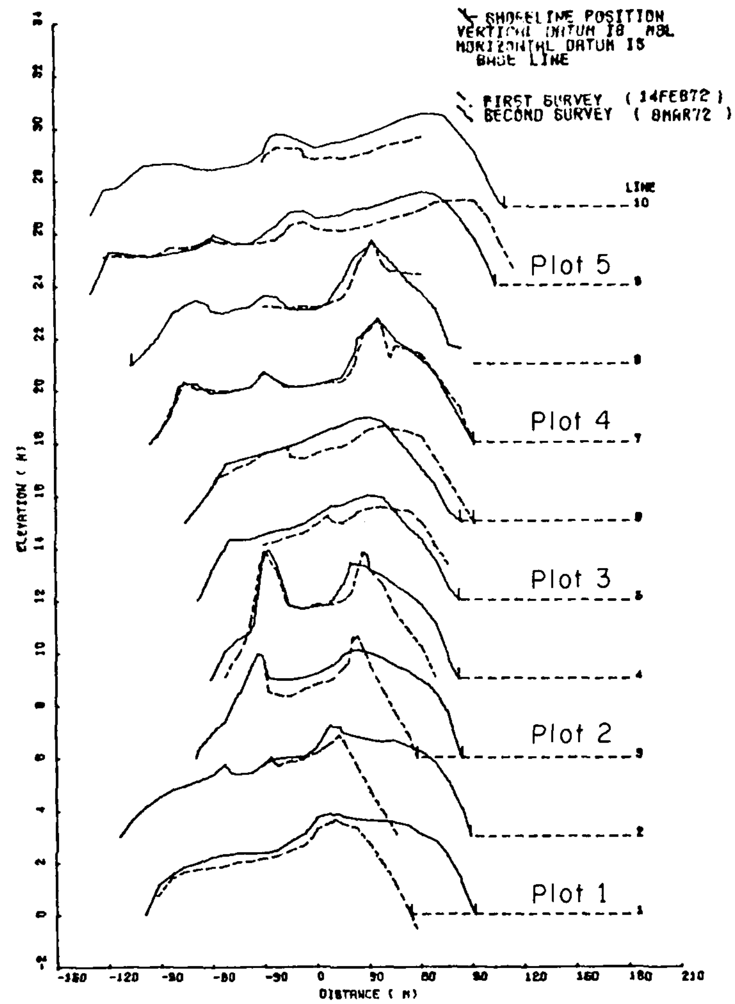

Figure B-1. Profile comparison for surveys of 10 profile lines at Nauset Beach, after February 1972 storm.

February 1972 storm. In all, 50 meters of the southern end of fence lifts one, two, and three were destroyed and lift four was damaged by the storm. Profile line 3 crosses the damaged section of plot 2 (Fig. B-1). Landward of the fences about 0.3 meter of sand was deposited. Little overwash occurred in the northern end of plot 2, profile line 4 (Fig. B-1). The straight fence section (plot 4) did not sustain damage during the February 1972 storm.

b. Storm of February 1978.

(1) Description. Though no elevational profiles were made after November 1977, seven observations were made after the severe storm on 6 and 7 February 1978. This storm tested the overall effectiveness of the dunes at Nauset Beach. The storm was the most severe to attack the northeastern

seaboard since March 1962. According to the New England Division, this storm has a recurrence interval of 75 years. Storm surge was recorded at Provincetown, Massachusetts, at 1.1 meters above a spring high tide of about 3.4 meters (G. Geise, Provincetown Center for Coastal Studies, personal communication, 1978). Breaking waves of 2.7 meters were observed on the U.S. Coast Guard Beach, 3 kilometers north of the test area.

(2) Impact. A field inspection in February 1978 revealed massive erosion on the seaward face of the experimental dunes. Of particular importance, however, is the fact that the plots were overwashed at only one location, the center of plot 3. Plot 3 was bisected by two foot and vehicular thoroughfares that had persisted since 1973. Figure B-2 is a ground photo of plot 3, showing the traffic area, taken in 1977, 4 months before the storm.

Figure B-2. Plot 3 (American beachgrass on 60-centimeter spacing), October 1977. Note foot and vehicular pathway through plot.

2. Long-Term Erosion and Accretion.

a. Shore Migration Adjacent to Test Plots. Figure B-3 compares the initial (April 1970) and final (November 1977) elevational profiles along the 762-meter test section at the south spit of Nauset Harbor. During the 91 months of monitoring, the landward shoreline in plots 1, 2, and 3 remained stable. The landward shoreline of plots 4 and 5 retreated about 15 to 18 meters, an annual erosion rate of about 2 meters per year. Erosion on the seaward shore followed the same general pattern. Annual erosion was less than 1 meter per year in plot 1 and more than 3 meters per year in plot 5. In general, the spit was relatively stable near its southern apex, while erosion was greater on both the seaward and landward shores of its more northern extremities.

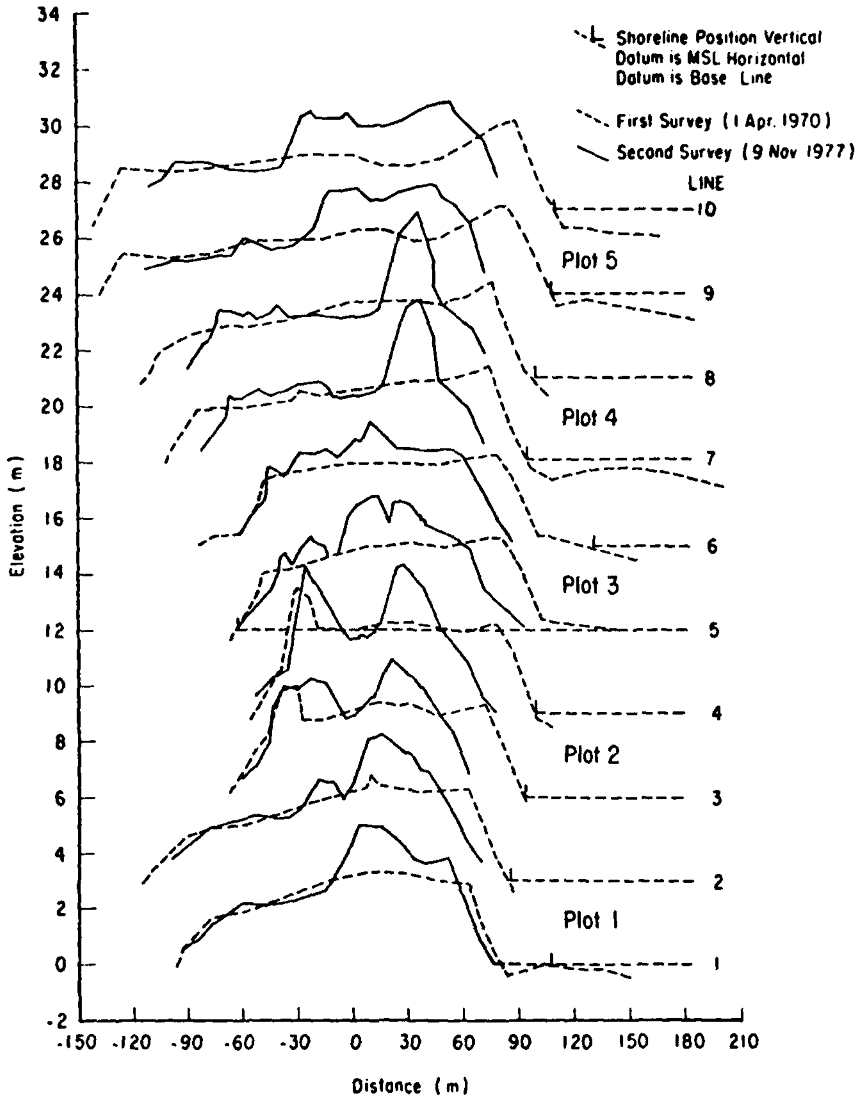

Figure B-3. Profile comparison for surveys of 10 profile lines at Nauset Beach for survey period, 1970-77.

b. Spit Migration. From 1856 to 1940, Nauset Inlet opened at the south end of Nauset Harbor. During this period the south spit was either quite short or completely absent (Zeigler, 1960). Since 1940 the south spit has elongated, though there have been several periods of retreat and progression. In October 1969, 6 months before the start of the experimental study, the length of the south spit was about 914 meters. By November 1977, the spit had increased to a length of 1,972 meters (Fig. B-4). Average annual extension of the spit was 110 meters (S. Onysko, U.S. Army Engineer Division, New England, personal communication, 1979).

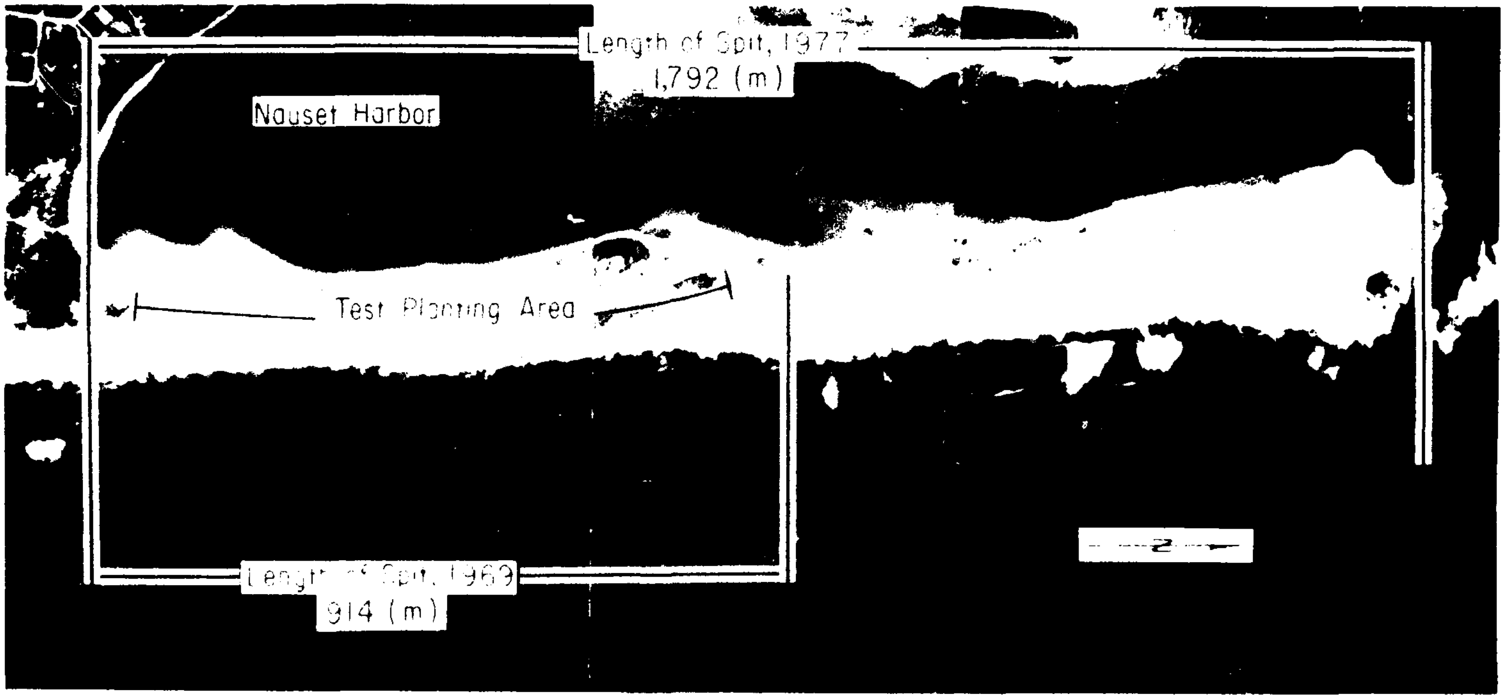

Figure B-4. Elongation of the Nauset Harbor south spit between 1969 and 1977.

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